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STATUS OF DSMT RESEARCH PROGRAM

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ABSTRACT

The status of the Dynamic Scale Model Technology (DSMT) research program is presented. DSMT is developing scale model technology for large space structures as part of the Controls Structures Interaction (CSI) program at the NASA Langley Research Center (LaRC). Under DSMT a hybrid-scale structural dynamics model of Space Station Freedom has been developed. Space station was selected as the focus structure for DSMT since the station represents the first opportunity to obtain flight data on a complex, three-dimensional space structure. Included in the paper is an overview of DSMT including the development of the space station scale model and the resulting hardware. Scaling technology was developed for this model to achieve a ground test article which existing test facilities can accommodate while employing realistically scaled hardware. The model was designed and fabricated by the Lockheed Missiles and Space Co., Sunnyvale, CA, and is assembled at LaRC for dynamic testing. Also, results from ground tests and analyses of the various model components are presented along with plans for future subassembly and mated model tests. Finally, utilization of the scale model for enhancing analysis verification of the full-scale space station is also considered.

SPACE STATION FREEDOM

Verification of analytical models for spacecraft has historically been accomplished through ground tests of space hardware prior to flight. Due to the large size and flexibility of current space structure designs, ground tests of full-scale hardware may be limited to components and subassemblies. An example of such a structure is the proposed design for Space Station Freedom, which consists of an erectable truss structure interconnecting a number of flexible components, payloads and modules. When fully assembled the station has planform dimensions of approximately 200 ft. by 550 ft., weighs approximately 600,000 lbs, and its lowest natural vibration frequency is much lower than 1 Hz. No practical method exists for verifying through ground tests an integrated configuration of this structure. Thus, analysis models for structural dynamics predictions will be verified primarily through synthesis of component analysis models.

Ground tests of dynamically scaled models offer a potential to verify analysis methods for prediction of dynamic characteristics of large, flexible space structures. The use of scale models for structures such as space station is relatively new, but scale models do have a firm historical basis in the aircraft and space launch vehicle fields. Although the scale model may not replicate exactly the full-scale hardware, it can be used to examine sensitivity of the complete system response to modeling accuracy at the component level. By using the same analysis methods for predicting the scale model dynamics as those proposed for the full-scale system, the accuracy and viability of those methods can be evaluated.

SPACE STATION FREEDOM

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DYNAMIC SCALE MODEL TECHNOLOGY

As part of the Control Structures Interaction (CSI) program at the NASA Langley Research Center (LaRC), the Dynamic Scale Model Technology (DSMT) project is developing scale model technology for large space structures. The objective of DSMT is to use scale models for verification of analytical methods for complex space structures which are too large to be ground tested. Space station was selected as the focus structure for DSMT since the station represents the first opportunity to obtain flight data on a complex, three-dimensional space structure. Under DSMT two laboratory models have been developed, namely, a generic simulated model and a hybrid-scale model. The scale model hardware consists of an erectable truss structure and includes many flexible components, modules and payloads which can be assembled to represent various stages of Space Station Freedom. Since the model is a good representation of space station it also provides a test-bed for examining some key technical issues such as understanding interactions between flexible components and the global truss structural modes.

DYNAMIC SCALE MODEL TECHNOLOGY

- **PROGRAM OBJECTIVE:**

  DEVELOP SCALE MODEL TECHNOLOGY TO VERIFY ANALYTICAL MODELS OF COMPLEX SPACE STRUCTURES TOO LARGE FOR GROUND TESTING.

- **FOCUS STRUCTURE IS SPACE STATION FREEDOM**

  - **REAL STRUCTURE TYPICAL OF FUTURE SYSTEMS**
  - **OPPORTUNITY FOR ON-ORBIT DATA**

- **TWO MODELS:**

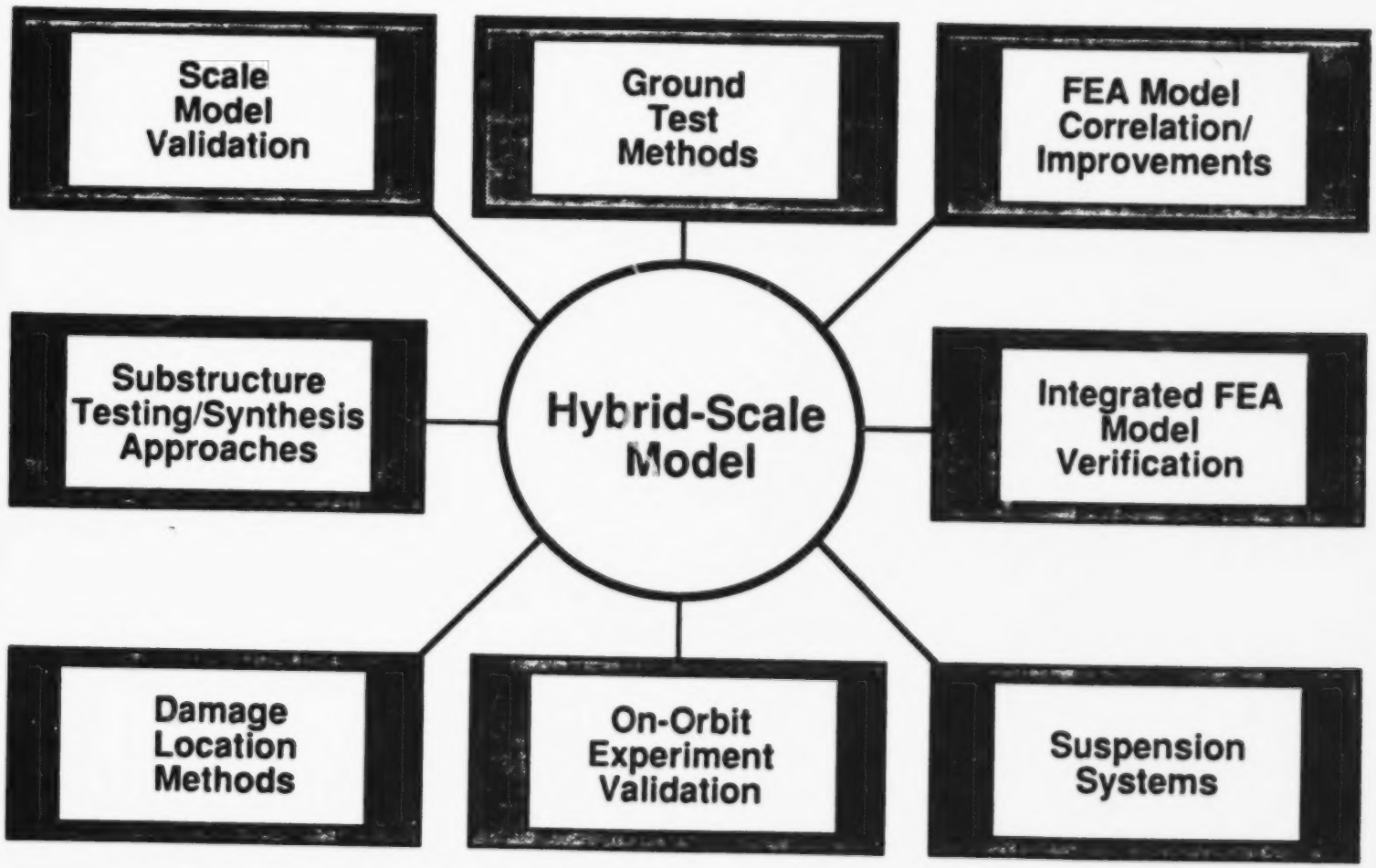
  1) GENERIC SIMULATED MODEL (NOT-TO-SCALE)
  2) HYBRID-SCALE MODEL

- **TEST-BED FOR USE IN EXAMINING KEY SPACE STATION FREEDOM DYNAMICS ISSUES.**

DSMT RESEARCH AREAS

Depicted in the figure are the main research areas which are being studied using the hybrid-scale space station model. Since DSMT is a technology program these research areas are selected to address broad technical issues pertaining to other spacecraft structures as well. The eight major areas are interrelated and essentially involve validation of scaling laws, verification and improvement of analysis models through ground vibration tests, development of advanced suspension systems, validation of on-orbit experiment designs, substructure synthesis approaches, and development of damage location approaches. In this paper only the scaling, ground test and analysis approaches are addressed.

DSMT RESEARCH AREAS



DSMT TEST/ANALYSIS VERIFICATION APPROACH

The approach adopted for verifying analytical models of the hybrid scale model consists of performing test/analysis updates at the component, substructure, and finally assembly sequence levels. As component models are refined that information is used to develop improved substructure analysis models which in turn lead to more accurate representations of the build assembly configurations. This approach parallels that of the full-scale space station program with the exception that DSMT can examine mated assembly configurations whereas space station cannot.

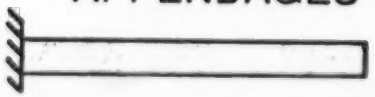
For the hybrid-scale HMB-2 model, the structure has been subdivided into twenty two components. These components are generally in one of four categories, namely, 1) truss structure, 2) appendages, 3) pallets, and 4) articulating joints. Each component will be individually tested and the corresponding analytical model will be updated to reflect the results of test data analysis. At the intermediate level substructures consisting of two or more components will be tested and analyzed to insure that the fidelity of the analytical model is preserved at all levels of complexity. Finally, the MB-2, MB-5, and MB-15 configurations will be studied to evaluate the primary object of this research program.

DSMT TEST/ANALYSIS VERIFICATION APPROACH

COMPONENTS → **SUB-STRUCTURES** → **ASSEMBLY SEQUENCE**

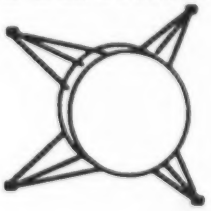
STRUTS-NODES

APPENDAGES

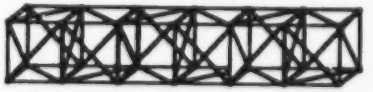


PALLETS

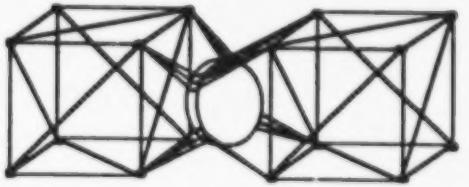
ARTICULATING JOINTS



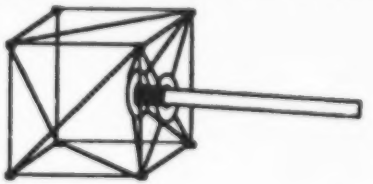
TRUSS STRUCTURE

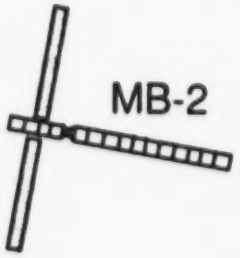


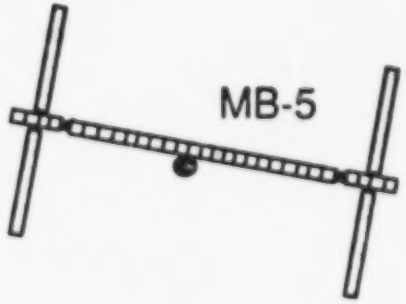
TRUSS/ALPHA-JOINT

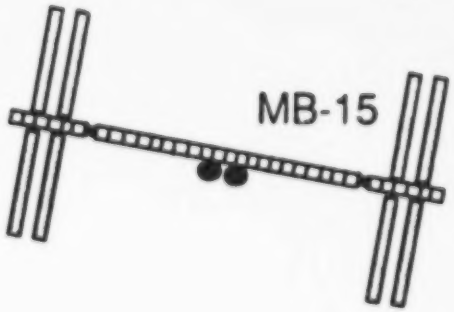


TRUSS/BETA-JOINT









1/10-SIZE GENERIC SPACE STATION MODEL (GMB-2)

The Generic MB-2 configuration space station model (GMB-2) is a 1/10-size simulated model utilizing commercially available truss hardware known as MEROFORM. In the figure the GMB-2 model is shown suspended in the configuration used for dynamic testing. The model was designed to simulate the dynamics of the more complicated hybrid-scale model. Simulated appendages were fabricated to have characteristics resembling the hybrid model. The model was used to study and evaluate analytical modeling and analysis techniques as well as experimental testing methods prior to examining the hybrid model.

1/10-SIZE GENERIC SPACE STATION MODEL (GMB-2)
CABLES
MASS FRAMES
PALLET
TRUSS
SOLAR ARRAY
RADIATOR
ALPHA-JOINT

QUALITY

SUSPENDED GENERIC MODEL TEST/ANALYSIS COMPARISONS

The generic GMB-2 model suspended by six cables was analyzed using an MSC/NASTRAN finite element model and was compared with the test results. An initial finite element model was developed based on component test/analysis correlations. This initial model still produced some inaccurate predictions of higher modes. An updated model which was in good agreement with test results was developed by performing additional model refinement especially at the main structural interfaces. Mode No. 4, the rigid body roll mode was improved because of the improved mass distribution of the components giving the correct roll mass moment of inertia. Several of the solar array and radiator modes dominated the equivalent system modes. Thus, the solar array and the radiator truss mounting plates were revised at the component level to correct the plate bending stiffness and match the static and dynamic response at the component level. These appendage modes matched the analysis at the component level and then correlated at the system level without additional adjustments.

SUSPENDED GENERIC MODEL
Test/Analysis Comparisons

FREQUENCY (Hz)

MODE	ANALYSES INITIAL	ANALYSES FINAL	TEST	DESCRIPTION
1	0.085	0.088	*	Yaw
2	0.118	0.117	*	Y Trans
3	0.118	0.118	*	X Trans
4	1.89	1.65	1.60	Rigid Roll
5	2.40	1.94	2.07	Rigid Pitch
6	2.59	2.56	2.49	SA OP B1 Sym
7	3.54	2.65	2.78	Z Trans + SA OP B1 Anti-Sym
8	3.14	2.74	2.89	SA OP B1 Anti-Sym
9	3.27	3.25	3.05	SA IP B1 Anti-Sym (Top SA IP B1)
10	3.38	3.38	3.28	SA IP B1 Sym (Bot SA IP B1)
23	5.88	5.70	5.97	Radiator OP B1
24	7.12	7.14	7.12	SA T1 Sym (Top SA T1)
25	7.16	7.21	7.34	SA T1 Anti-Sym (Bot SA T1)
32	12.95	9.10	8.17	Truss X-Z B1
33	-	9.36	*	Twist of 2 Bay Section
38	13.48	9.84	8.94	Truss X-Y B1
55	17.54	17.47	19.91	Radiator IP B1
56	17.63	17.75	17.76	SA OP B2 Sym (Except Mid Pts)
61	16.53	18.39	19.09	SA OP B2 Anti-Sym

SA: Solar Array, OP:Out-of-Plane, IP:In-Plane,
B1:1st Bending, B2:2nd Bending, T1:1st Torsion
* Did not measure

DSMT HYBRID-SCALE MODEL

Shown in the figure is a hybrid-scale structural model of an early Space Station Freedom assembly configuration (MB-2). Hybrid-scaling refers to the ,1/5:1/10 scale factor applied to the model design. Hybrid scaling technology was developed for this model to achieve a ground test article which existing test facilities can accommodate while employing realistically scaled hardware. All truss planform dimensions have been scaled to 1/10-size of the full-scale station design. The truss nodal joints, mass and frequencies are 1/5-scale. This design provides a model which can be tested in existing facilities, yet has the low frequency dynamics characteristic of the station structure. The model was developed by the Lockheed Missiles and Space Company, Sunnyvale, CA. The MB-2 configuration consists of ten truss bays which are connected by an articulating rotary joint and on which a number of solar arrays, radiators and pallets are mounted. Ground tests of this model will be performed at LaRC to develop techniques for predicting the on-orbit dynamic response of such structures.

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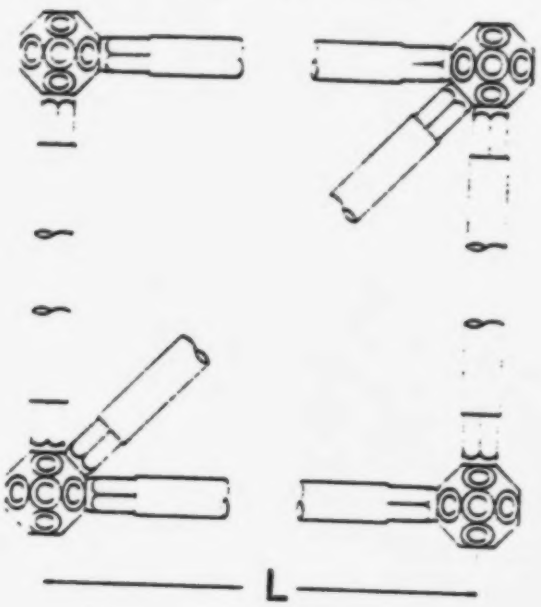
DSMT HYBRID-SCALE MODEL DYNAMICS

Hybrid scaling provides a dynamically scaled space station model such that a realistic test article can be obtained for developing test and suspension techniques required for verifying analytical models. Hybrid scaling employs classical distorted scaling techniques, which have historically been used extensively for wind tunnel models. When used for large space structures it permits the use of different scale factors for the truss structure components, appendages and payloads while sacrificing local dynamic behavior, but retaining overall global dynamics behavior. The hybrid-scale model truss structure bay size and truss joint components were selected to be 1/10 and 1/5 scale, respectively. This results in a model which is small enough (50' x 30' planform) to be assembled and tested in an existing LaRC facility. Furthermore, the 1/5-scale joints are essentially the minimum size at which erectable joints can be fabricated without incurring large manufacturing costs or compromising joint performance. Properly distorting the truss component stiffnesses and masses yields a model which possesses the same global dynamic properties as would a fully 1/5-scale replica model. Some of the scale factors which apply to the hybrid model are listed in the figure.

DSMT HYBRID-SCALE MODEL DYNAMICS

FULL SCALE



1/10 SCALE REPLICA

SIZE

1/5 : 1/10 HYBRID SCALE

1/5 SCALE REPLICA

JOINT = TUBE DYNAMICS

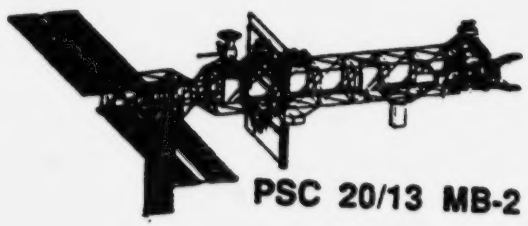
HYBRID-SCALE QUANTITY	=	SCALE FACTOR	*	FULL-SCALE QUANTITY
SIZE		1/10		SIZE
MASS		1/125		MASS
FREQUENCY		5		FREQUENCY
FORCE		1/25		FORCE
ACCELERATION		5		ACCELERATION
DISPLACEMENT		1/5		DISPLACEMENT

DSMT HYBRID-SCALE MODEL FEATURES

The DSMT hybrid-scale model utilizes erectable joints and modular components such that any number of space station configurations can be assembled. This allows the model to be representative of each of the approximately 20 assembly flights required to reach the assembly complete station. Depicted in the figure are the three focus configurations selected for study. The MB-2, MB-5, MB-15 designations refer to space station mission build configuration numbers. As seen in the table these three structures span a wide range of structural parameters. Also, by varying mass properties of the payload components, the hybrid-scale model structure can be adjusted to reflect changes in the station design.

DSMT HYBRID-SCALE MODEL FEATURES

- ERECTABLE JOINTS AND STANDARDIZED COMPONENTS PERMIT TESTBED TO BE ASSEMBLED IN ANY CONFIGURATION
- MASS PROPERTIES OF MANY COMPONENTS CAN BE ADJUSTED VIA MODIFICATION OF LUMPED WEIGHTS



PSC 20/13 MB-2

PSC 20/13 MB-15

PSC 20/13 MB-5

1/5:1/10 Scale	HMB-2	HMB-5	HMB-15
Dimensions (ft)	19 x 23	35 x 23	48 x 23
Weight (lbs)	363	1306	3621
Freq Range (Hz) (1st 10 Sys Modes)	5 - 37	2 - 8	1 - 7

DSMT GANTRY TEST FIXTURE

The gantry fixture is the support structure for the DSMT hardware. The fixture is capable of supporting various configurations of the DSMT space station model. There are currently two working platforms at 20 ft. and 40 ft., and the gantry can be expanded to 60 ft. These platforms allow for numerous support locations as well as various support mechanisms. The structural characteristics of the gantry are known and uncoupled from the current suspended models. Provisions were made to have the capability to remove some structural members from the gantry for positioning of large models.

DSMT GANTRY TEST FIXTURE

FEATURES

- Provides a test fixture with predictable dynamics uncoupled from model dynamics.
- 40 foot height, expandable to 60 feet.
- Wooden work platform allows numerous cable attach points.
- Can accomodate an evolutionary space station configuration including a scaled space shuttle.

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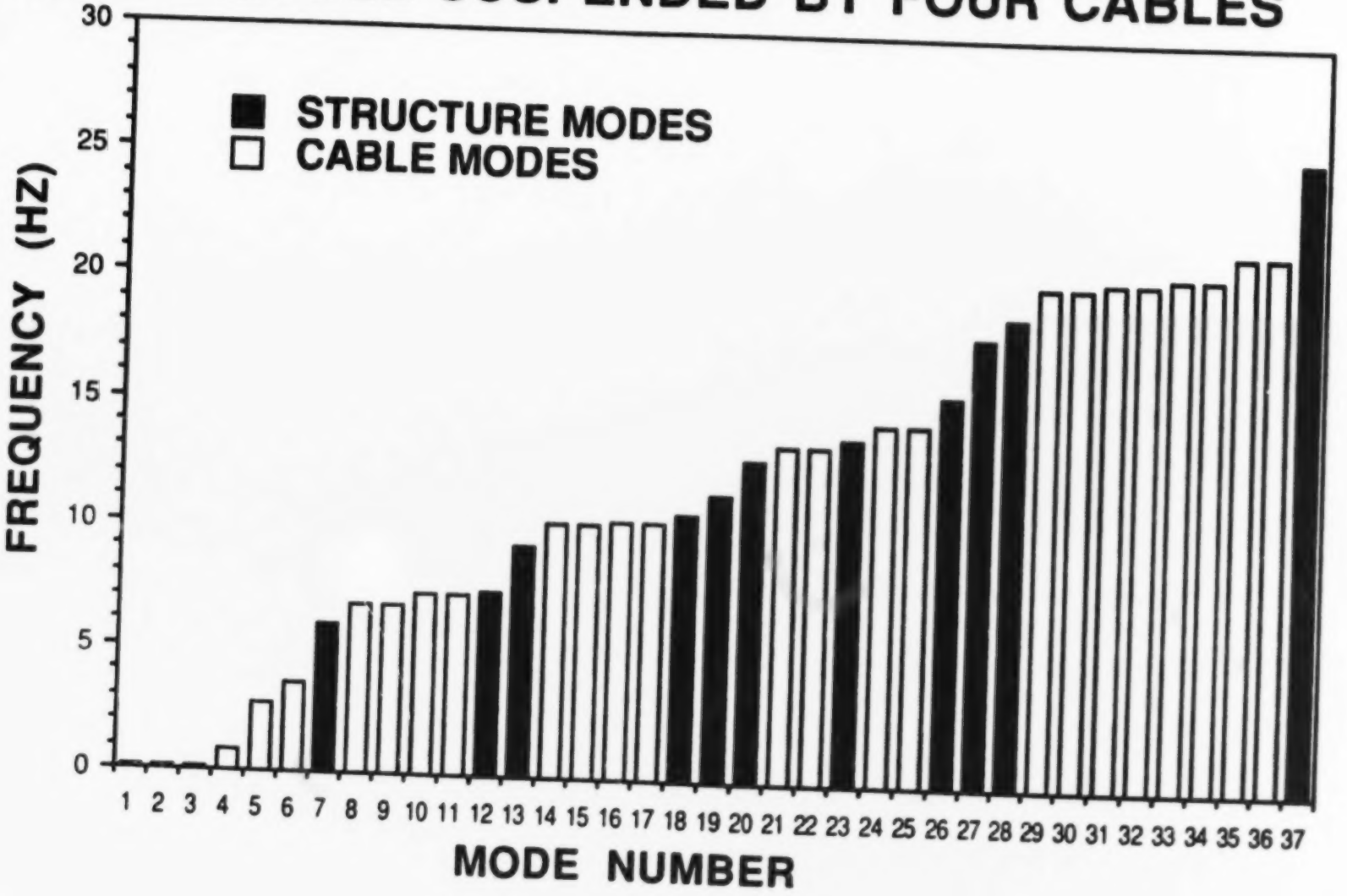
VIBRATION FREQUENCIES FOR HYBRID-SCALE HMB-2 MODEL SUSPENDED BY FOUR CABLES

The hybrid-scale HMB-2 model suspended by four cables was evaluated using an MSC/NASTRAN finite element model. Depicted in the figure is the modal density for this structure in the suspended configuration. There are 37 modes in the frequency range of interest from (0-25 Hz), 11 of these modes are considered global structural modes. Analysis of this structure required that the cable forces needed to keep the model level due to gravity loading be determined using a static analysis. The second step was to perform a non-linear analysis imposing preload cable strains and gravity forces to arrive at the deformed level position with the correct cable forces. The final step was to perform the normal modes analysis using a combined stiffness matrix consisting of the elastic stiffness plus the differential stiffness due to the internal forces from the second step.

VIBRATION FREQUENCIES FOR HYBRID-SCALE HMB-2 MODEL SUSPENDED BY FOUR CABLES



DSMT COMPONENT TEST/ANALYSIS RESULTS

A number of components from the HMB-2 scale model have been examined to date. Listed in the figure are the test/analysis correlations for six components. The initial analysis models were based on preliminary design information and were developed prior to fabrication of the hardware. These models were updated based on the results obtained from the analysis of the test data associated with each component. In performing the analysis updates the geometry, mass distribution, and stiffness characteristics of components are examined and corrected as part of the verification process. In addition, design sensitivity analysis methods are used to examine the influence of various physical and material properties on the component structural characteristics. Information from the resulting component analysis models are now being included in a new analysis model of the assembled HMB-2 structure.

DSMT COMPONENT TEST/ANALYSIS RESULTS

HMB-2 MODEL WITH RIGID APPENDAGES

	FUNDAMENTAL FREQUENCY (HZ)		
COMPONENT	INITIAL ANALYSIS	FINAL ANALYSIS	TEST
EPS RADIATOR	46.19	44.17	43.53
SOLAR ARRAY	21.29	19.83	18.87
TCS RADIATOR	26.36	23.45	23.10
BETA-JOINT	157.0	72.70	69.70
TRUSS LONGERON	22.09	19.74	19.75
ONE TRUSS BAY	92.17	77.80	77.90

POTENTIAL VERIFICATION MATRIX FOR ON-ORBIT STRUCTURAL DYNAMICS PREDICTION

For a structure as complex as the space station numerous programs are required to develop a verification matrix which will allow the accurate prediction of structural dynamics of the mated structure in zero-g. As shown in the table, DSMT is one important element in such a matrix, but it alone is not sufficient for complete analysis verification. DSMT does provide verification of analysis at both the component and mated levels, but in a 1-g environment. The MODE experiment provides a zero-g verification of similar hardware to DSMT, but only at the component level. In addition, there will be component level full-scale ground tests of space station hardware. Finally, the proposed MIE project will provide on-orbit data from components, which are instrumented on the station, and on the mated station for final analysis verification.

POTENTIAL VERIFICATION MATRIX FOR ON-ORBIT STRUCTURAL DYNAMICS PREDICTION

	SUB-SCALE		*FULL-SCALE*	
	COMPONENT	**MATED**	**COMPONENT**	**MATED**
1-g	DSMT Program	DSMT Program	S.S. Freedom Project	
0-g	MODE Experiment		MIE Project	MIE Project

DSMT=Dynamic Scale Model Technology (NASA LaRC)
MODE=Mid-deck On-orbit Dynamics Experiment (MIT/NASA LaRC)
MIE=Modal Identification Experiment (NASA LaRC)

▨ Goal for On-orbit Structural Dynamics Predictions

CONCLUDING REMARKS

DSMT is a technology program which has Space Station Freedom as a focus structure. The hybrid-scale model hardware is the nucleus of a broad based research effort which includes the development of ground tests and analysis methods for a large class of structure. Due to the resemblance of the scale model to space station, DSMT does provide a ground test-bed for examining key technical issues. Also, the approach for analysis verification does parallel that proposed for space station, with the added benefit of providing mated structure test/analysis correlation. Finally, the use of scale models should be considered an integral part of an overall verification plan for a complex space structure.

CONCLUDING REMARKS

- DSMT IS A TECHNOLOGY PROGRAM WITH SPACE STATION FREEDOM AS A FOCUS STRUCTURE.
- GROUND TEST/ANALYSIS OF MODEL HARDWARE PROGRESSING WELL.
- SCALE MODEL HARDWARE PROVIDES GROUND TEST-BED FOR EXAMINING SPACE STATION TECHNICAL ISSUES.
- APPROACH FOR ANALYSIS VERIFICATION EXPLOITS USE OF COMPONENT LEVEL TEST/ANALYSIS UPDATES.
- SCALE MODELS ARE AN INTEGRAL PART OF ON-ORBIT STRUCTURAL DYNAMICS ANALYSIS VERIFICATION.

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16. Abstract

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